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UNITED STATES GEOLOGICAL SURVEY

No. 5

IRRIGATION PRACTICE ON THE GREAT PLAINS.—COWGILL

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1897

UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

IRRIGATION PRACTICE ON THE GREAT PLAINS

BY

ELIAS BRANSON COWGILL

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Department of the Interior,
United States Geological Survey,
Division of Hydrography,
Washington, March 3, 1897.

Sir: I have the honor to transmit herewith a paper entitled "Irrigation Practice on the Great Plains," by Prof. E. B. Cowgill, and to recommend that it be published in the series of papers upon water supply and irrigation. Professor Cowgill's experience as a practical farmer and irrigator and as the editor of an agricultural paper renders his observations upon irrigation practice of especial value in discussions of the methods of utilizing the water resources of semiarid areas.

Very respectfully,

F. H. Newell,
Hydrographer in Charge.

Hon. Charles D. Walcott,
Director United States Geological Survey.

IRRIGATION PRACTICE ON THE GREAT PLAINS.

By E. B. Cowgill.

GENERAL STATEMENT.

The characteristics of topography and climate which influence the practice of irrigation on the Great Plains may be summed up in the general statement that the land is usually smooth, the soil extremely deep and fertile, the rainfall scanty and irregular, the sunshine abundant, and the water supply variable and uncertain. In seasons of unusual rainfall a stranger entering western Kansas is astonished that a land of such remarkable productiveness has been almost abandoned since its first settlement. Coming again after a season of deficient rainfall he would be equally surprised that anyone could have been tempted to try to make a living on the barren prairies. Happening upon a spot where irrigation is practiced, he at once appreciates the enormous importance that water bears to the successful settlement of the country, for there agriculture on a small scale is profitable no matter what may be the character of the season; there all of the elements—soil, sunshine, and water—combine to produce a fruitful increase of plant life.

The water supply of the region, at best scanty, is yet ample for the development of considerable areas, far greater than are at present occupied. In this paper it is not proposed to discuss what or where these sources are, but, assuming that water is to be had from surface streams, storm waters, or wells or other underground sources, the attempt is made to describe in a general way to the farmers, especially to those who have not practiced irrigation, the methods of controlling, storing, distributing, and applying the waters to the cultivated fields. It is recognized that no description can ever take the place of actual experience, but it is possible to give general directions which the individual farmer, by experiment and observation, can adapt to his peculiar needs.

RESERVOIRS FOR STORM WATERS.

Artificial reservoirs have been found a necessity in the irrigation of the plains. Storm waters can not be controlled or directed upon the land as they fall. They run off from the hard, sun-baked prairies in torrents, especially in those portions of the country where reliance must be placed chiefly on such waters. For the storage of this water reservoir sites are easily found, and are usually selected with a view to impounding the water from a considerable drainage area. The retaining dams are of various sizes, according to the needs and the means of the persons constructing them. A reservoir to contain an acre or so of water is easily made by placing an earthen dam across the outlet of the drainage area, even though the slopes may be very gradual. The dam has not usually to be built very high, and the principal precaution necessary is to provide against washing out in time of freshet. The larger reservoirs differ in no essential from the smaller, except that the sites must be selected with reference to larger areas of drainage, and the dams usually require more work, both as to engineering and construction.

A typical example of this kind is the reservoir of George M. Munger, of Greenwood County, Kansas. Mr. Munger is engaged extensively in orcharding, having 500 acres of fruit trees ready to bear. Notwithstanding his location near the ninety-sixth meridian, far within what is usually designated as the "rain belt," he has concluded, after careful investigation of the subject, that the realization of the expected profits of his orchard is dependent to a large extent upon the artificial application of water. There are no surface streams near from which to obtain water in the usual way. There is on his farm, however, an eligible site for a storm-water reservoir. But most of his orchard and farming land is at a higher level than the reservoir site, so that, after collecting the water, he is obliged to pump it.

The accompanying view, Pl. I, gives the relative location of the orchard and source of water supply. The storm reservoir can be seen in the distance to the left, while between it and the orchard is the pumping station. The ravine in which the dam is placed runs diagonally through the farm. The sides of it have a gentle slope, thus necessitating the construction of a dam of considerable length, as shown in the illustration, Pl. II. In order to provide a safe and sufficient spillway, it was necessary to build the dam to considerably larger dimensions than would otherwise have been essential. The topography is such that water could be wasted over a natural ridge having a breadth of about 1,000 feet. It was therefore decided to carry the dam to a sufficient height above this ridge to hold in check any freshet of unusual size and turn it over the crest of this depression.

The watershed above the point at which the dam is located is about 800 acres in extent. The valley shows by watermarks that the high

MUNGER ORCHARD, GREENWOOD COUNTY, KANSAS.

Part of a 500-acre orchard irrigated with storm water.

MUNGER RESERVOIR DAM.

A 90-acre storm-water reservoir on farm of G M. Munger, Greenwood County, Kansas.

floods spread out to the width of about 300 feet. The dam is 2,582 feet long, 192 feet broad at the widest part of the base, and a little less than 40 feet at the highest point above the bottom of the valley. The estimated area of water when full is 160 acres, and the estimated capacity 1,600 acre-feet.[1] It was expected that two years of average run-off would fill the reservoir.

In the construction of the dam, which was built exclusively of earth, the sod was entirely removed and placed at the rear face. The old water channel was thoroughly cleansed of the washed-in gravel, and the work begun with new earth. The soil is a heavy clay with the usual variations, including probably a full supply of gumbo and alkali.

The matter of seepage through the dam and the method of correcting it was considered by Mr. Munger, who states in general terms that while the authorities on the construction of earthen dams recommend that the earth be especially selected for the face, and a puddle trench be placed in the heart of the work, it seemed difficult to formulate a scheme for so doing that did not involve too great expense. Earth was taken as it came in the borrow pits, and in each successive pit was used as deep as it could readily be obtained. All earth was taken from inside the work, except where it could not be had without too great a haul. Several smaller dams had been previously constructed on the place, and in each and every place there was a seepage along the toe of the dam, but in no case was it sufficient to endanger the stability of the work. The same trouble developed in this work, and on account of the magnitude of the dam it was deemed expedient to correct it. This was accomplished by running a permanent stone drain along the toe of the dam, grading it to the lowest point possible, and running laterals to every seepy spot that showed. The result was very satisfactory, there having been a small stream running from the drain constantly since its construction, but now materially reduced in volume.

The original estimate shows about 100,000 cubic yards as the earth contents of the dam, but, on account of the action of the waves on the surface of the dam, it was found that the estimate was considerably exceeded. It was found impracticable to prevent, by riprapping, the water from bringing the face of the dam to the natural grade, so that no protection had been provided against the action of the waves until the grade determined by the water was made, when the face of the dam was riprapped to prevent further loss of earth from the action of the waves.

Except for the fact that Mr. Munger has many hundreds of acres of land to irrigate, so large a construction would not be advisable, but the plan of this reservoir and the methods pursued in its construction

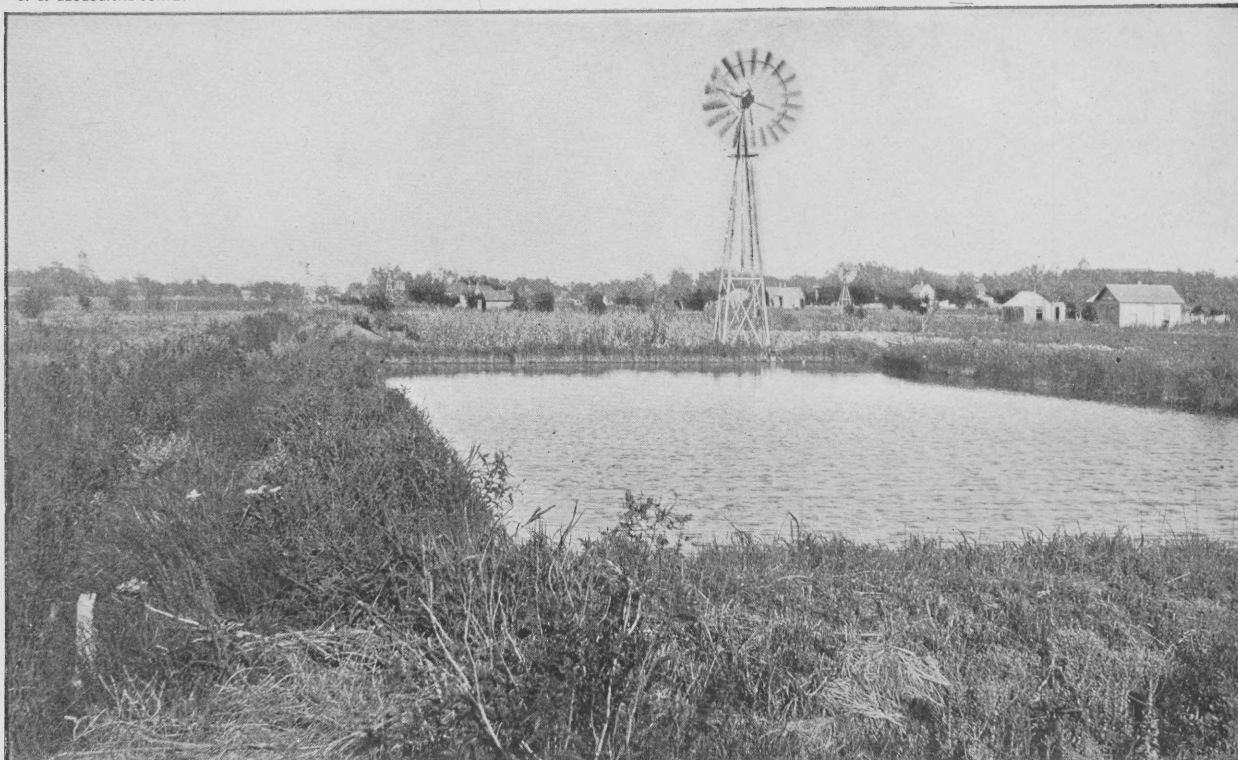
[1] Irrigating a 500-acre orchard, by George M. Munger: Report of the Kansas State Board of Agriculture for the quarter ending March 31, 1895, pp. 66-71.

may well be taken as models by those whose requirements demand reservoirs of only moderate size. Water may be drawn through a flume for the irrigation of considerable areas of Mr. Munger's farm which lie at a lower level than that of the water in the reservoir, but for most of the farm it is necessary to raise water. This is done by two compound, duplex, direct-acting steam pumps of a daily capacity of about 4,000,000 gallons, which forward the water rapidly enough to make unnecessary a distributing reservoir from which to draw the water when supplying it to the land.

RESERVOIRS FOR PUMPED WATER.

Reservoirs for pumped water differ in several respects from those for storm water. The site for a pumped-water reservoir should be selected on the highest part of the land to be irrigated. The form will not usually be determined by the contour of the land, but by the taste or convenience of the irrigator. Not infrequently such reservoirs are made square, or at least rectangular. Some are made circular, thus securing the greatest content for a given amount of embankment. In size, pumped-water reservoirs vary from quite small, as shown by Pl. III—say 30 feet square—to those containing half an acre or an acre of ground. Irrigation with pumped water has been confined to small operations, at least in Kansas and upon the Great Plains, making large storage capacity unnecessary. Since pumping into the reservoir is done almost exclusively with windmills, the work of which varies with the wind, it is sometimes thought that the size of reservoir, compared with the land irrigated, should be considerably increased above the dimensions now in common use. But the practice has been to use the reservoir as an accumulator, giving the irrigator command of his water supply rapidly, rather than as a store against the time when water may not be obtained by the aid of the wind. Experience has confirmed the practice of using the reservoir merely as an accumulator, except for large gardening operations, for which a delay in the application of water sometimes proves disastrous. With other crops it is found quite possible to anticipate probable scarcity by storing abundance of moisture in the porous subsoil. The relative size of the reservoir to the land to be irrigated averages from about 1 to 80 to about 1 to 100.

The depth of the reservoir when first constructed is generally 4 feet; that is, the bank which constitutes the dam all around the area to be filled with water is raised about 4 feet above the natural surface of the soil, as shown in fig. 1. The earth for the construction of the dam is usually taken from within the reservoir, so that the depth of water in the reservoir would be somewhat more than 4 feet if it were filled to the top of the bank.



SMALL IRRIGATION RESERVOIR, AT GARDEN, KANSAS.

Reservoirs are, as a rule, made on land which has been under cultivation. In preparing for the work all trash should be removed and the ground which is to serve as the foundation of the dam should be about four times as broad as the height of the proposed embankment around the reservoir. It is a good plan in plowing this foundation to turn the furrows so as to leave a dead furrow in the middle and then to pump water into this dead furrow, wetting all the base of the dam

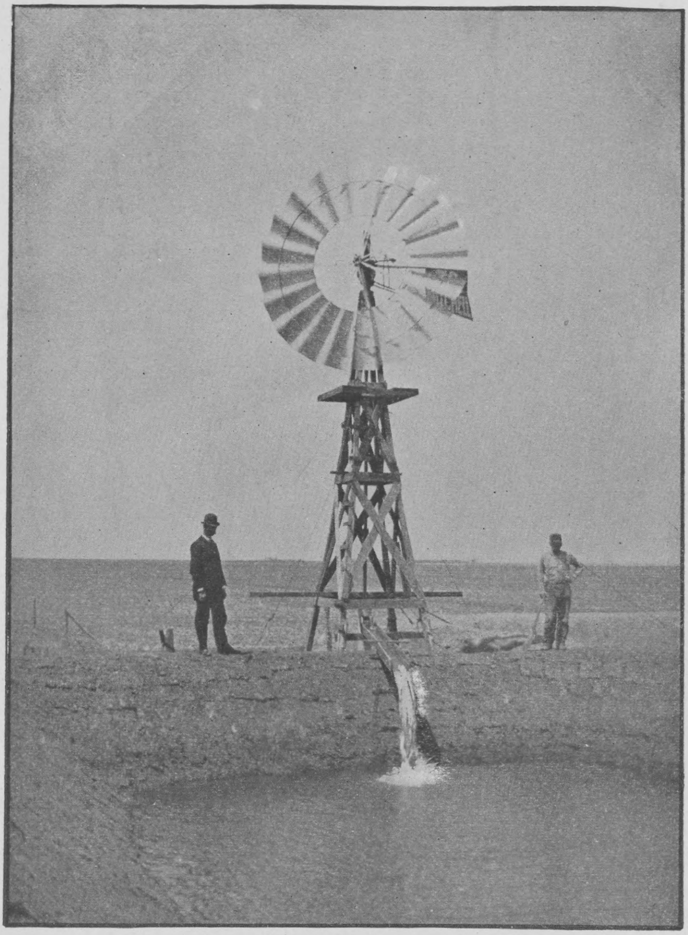


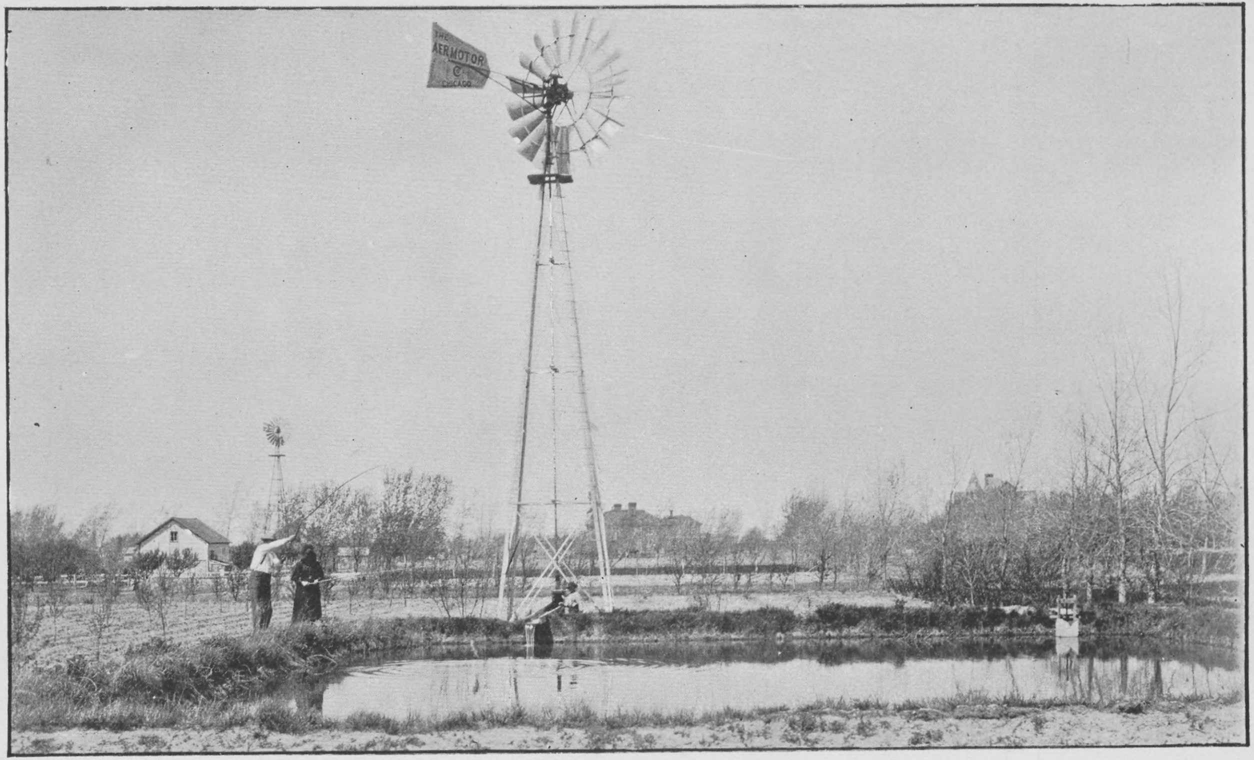
FIG. 1.—Reservoir and windmill north of Garden, Kansas.

thoroughly. After this has sufficiently settled to admit of driving over it, it is well to tramp it by driving horses or other heavy animals over it until it is well compacted. The land in the interior of the reservoir is plowed and the loose earth is removed to the embankment, usually with the ordinary slip scraper, although in the construction of very large reservoirs wheeled scrapers are sometimes used.

In depositing the soil which is to constitute the embankment, it is better to keep the parts which will become the faces higher than the center, thus leaving a channel all around through the whole of the embankment. At the close of each day's work care should be taken that this channel be continuous, and that the top of the embankment be about the same height all around, so that water may be pumped into the channel in the heart of the bank, thoroughly soaking it. In soils at all likely to seep it is very important that the precaution of soaking the bank daily as it is built be observed. If not made too soft in the evening, it will usually be in condition to tramp in the morning, and this should be done by driving repeatedly around on top of the embankment made. If each day's work is treated in this way, there will be little trouble from seepage through the bank of the completed reservoir.

The crumbling soils of Kansas will usually take about the correct form for a bank as deposited from the scraper and under the tramping here recommended. Some who prefer to have the banks steeper than they are usually left in this way trim them up with a shovel, afterwards sodding to prevent further crumbling. This answers very well for the outside of the dam, and sod used inside, as shown in fig. 1, is a protection against washing until the soil shall have become so thoroughly settled as to be less affected by the action of the waves. If the reservoir be small, it is sometimes inexpedient to take from the interior the entire amount of earth required for the embankment. Experience has shown that soil near the surface more readily becomes a water holder than does that from the substratum. In any case it is not safe to employ the gravelly subsoil which prevails almost everywhere in the larger valleys of western Kansas.

After the completion of the bank, the next work is to make the bottom of the reservoir water-tight. This is done by plowing the entire area to a depth of 3 or 4 inches, harrowing it fine, and then pumping in enough water to cover the entire bottom—if, indeed, it does not seep out too fast to admit of this. In any case, water should be pumped in until a considerable area is thoroughly soaked. As soon as this is settled sufficiently, so that heavy animals will not sink in more than 6 or 8 inches, horses or cattle are turned in and driven around over the water-soaked area until it becomes hard. Then more water is pumped in and a larger area soaked. It is usually found that after the first partial soaking and the subsequent tramping the entire area of the bottom may be covered with water. Enough water should be put in to thoroughly soak every foot of the area, so that it would be dangerous to immediately take large animals into it. After a few days, however, this will have settled so that animals may be safely driven over it, when it should be tramped continuously until it becomes so hard that the hoofs of the animals scarcely mark it. Such puddling rarely fails—even in very open soils and in those which seem to be nearly all sand—to make a reservoir so tight that the



SMALL RESERVOIR, SHOWING WINDMILL AND OUTLET, AT GARDEN, KANSAS.

seepage under 4 feet of water is insignificant. In rare cases it may be necessary to throw in manure, or at least straw or hay, and again soak and tramp, but generally there is enough organic matter in the surface soil to puddle sufficiently without the addition of any other material. Some preparations have been advertised as linings for reservoirs, but the cheapest and undoubtedly the best lining is as deep puddling as can be done with heavy animals.

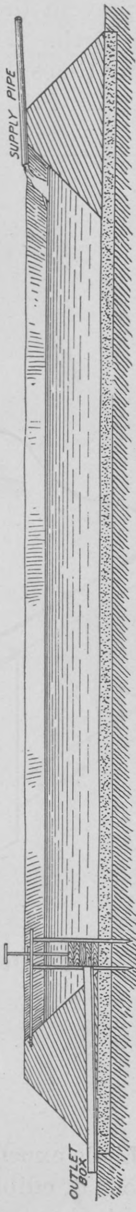


FIG. 2.—Diagram of reservoir and outlet.

Every reservoir must, of course, be provided with a suitable outlet for the water, and unless careful attention to the pumping can be relied upon there should be also an overflow or waste-way. The outlet flume should be provided when the reservoir is laid out and before the banks are completed. The bottom of the outlet should be placed as low as the bottom of the ditch outside, as shown in fig. 2, but is usually not so low as the bottom of the reservoir inside, so that the water is not all drawn from the reservoir. It is found that reservoirs retain their ability to resist seepage better if never entirely drained. This is especially true in the winter season, when, if allowed to freeze, the puddling of the bottom frequently becomes so deteriorated as to necessitate renewal. The flume should be long enough to reach entirely through the embankment. It is usually made of 2-inch planks, with a clear opening of 6 by 8 inches. Where large areas are to be irrigated, making rapidity of supply essential, the box should be made larger, and for field work an opening of 12 by 16 inches will be found ample. It is not always necessary to use the full size of the opening, but the flow is regulated by the extent to which the valve or gate is raised.

Several forms of valve have been used. An excellent one is shown in the illustration, fig. 3, from a Kansas experiment station bulletin.[1] This gives a perspective view of the outlet box with guides attached for holding the valve or gate. This is faced with leather securely held by tacks. The gate is best operated by a carpenter's bench-screw attached to a suitable support and engaging a nut on the upright standard. An efficient gate is also shown in the illustration, Pl. IV, operated by a lever and rod extending through the outlet box. Whatever form of flume is used, it is better to have one or two bands of cleats around it, taking care that

[1]Small fruits by irrigation: Experiment station, Kansas Agricultural College, Bulletin No. 55, December, 1895, p. 134.

they fit water-tight to the planks. In placing the flume it should be very thoroughly embedded in the bank, care being taken to ram the earth firmly against the planks, especially on the under side, in order to prevent the water from creeping along between the planks and the earth. The extra work in properly bedding the flume is worth many times its cost in security against leaks.

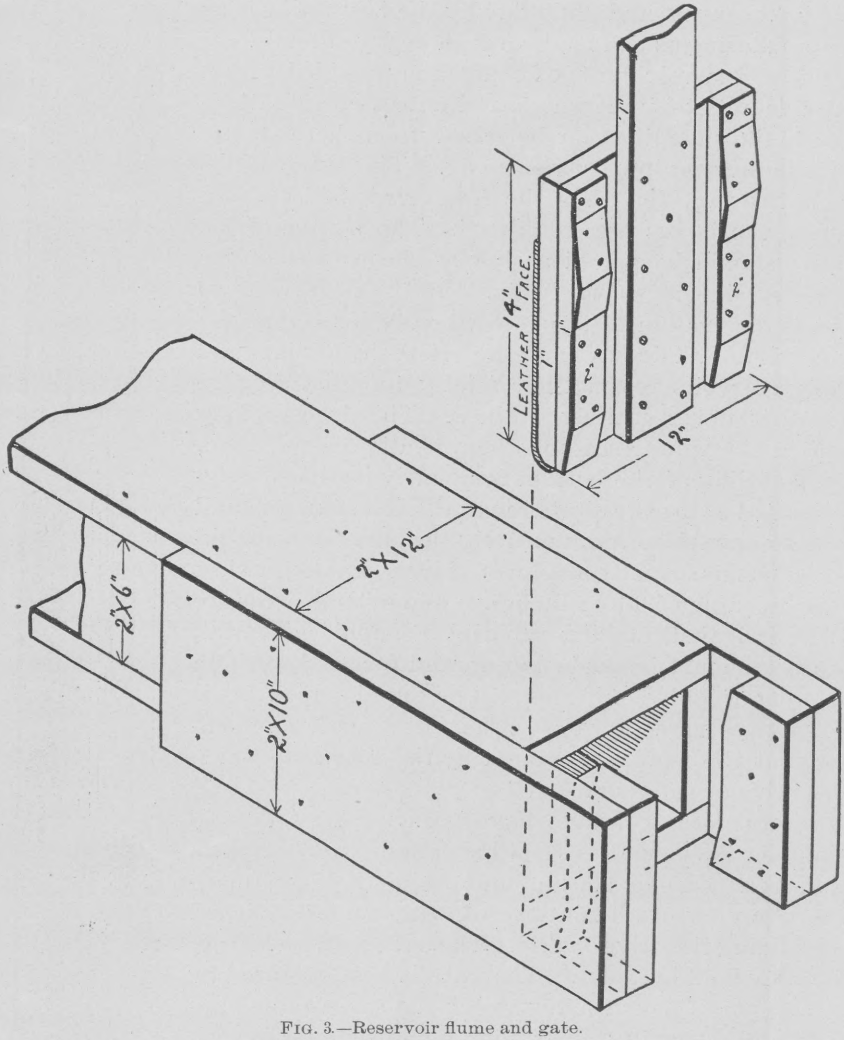


FIG. 3.—Reservoir flume and gate.

Little expense is needed to prepare an irrigation reservoir for the abode of edible fishes. It is requisite, however, to place wire screening in front of the gate, so that when water is to be drawn from the pond no fish can pass through the flume. A light framework is usually constructed, of such dimensions as to allow the gate to be opened without interfering with it, and this is covered with common wire netting, of the sort used for fly screens. This rusts out somewhat readily,

RESERVOIR AND IRRIGATED FIELD, AT GARDEN, KANSAS.

but is cheap and easily renewed. Screens of brass wire, while costing more at the outset, last much longer. The water as pumped from the wells into the reservoir is perfectly clear, and is usually at a temperature of about 58° F. This is not ideal water for the abode of carp; nevertheless, this variety has been more cultivated than any other, largely on account of its prolific increase. The growth of the carp is, however, somewhat disappointing, and this is probably due to the fact that, owing to the continual additions of the cold well water from the pump, the temperature of the water is below that at which the fish thrives best. Channel cat, crappie, and black bass have been found to do well. Some attempts have been made to grow trout in these ponds, but without success.

If irrigation reservoirs are not otherwise used in the winter, they form excellent ice ponds, and make available what would otherwise be an expensive luxury. But if water is continually pumped into the pond, especially in the more southern portions of the district, ice is but scantily formed. It is possible, however, for a farmer who has a reservoir to provide himself with a sufficient supply for the dairy and other purposes, even though he use his reservoir for irrigation during much of the winter.

DITCHES.

Not every tract of land has such conformation as renders irrigation practicable. Land the surface of which is formed into mounds of considerable magnitude may well be discarded, at least until that of more even contour shall have been brought under irrigation. Ridges and terraces are not especially objectionable features. It scarcely seems necessary to remark that irrigation is practicable only where water can be induced to flow over the land, and that water will not flow uphill, although the eye is often deceived and the novice at his first observation of the use of water through irrigation ditches receives the impression that in some parts of the work water is actually flowing up grade. And the most practiced are sometimes, indeed frequently, mistaken as to whether the surface of the land rises or falls in a given direction. It is therefore important, in the location of ditches, that a preliminary survey of the land be made; and it is a good plan to make a contour map of the land to be irrigated before locating the ditches. In irrigating from reservoirs it is essential, as before stated, that the reservoir be placed on the highest part of the land to be irrigated.

Ditches, as well as reservoirs, should be kept on land at least as high as, and generally a little higher than, that to which they are to supply the water. One of the largest and most successful irrigators of farm crops on the plains, C. D. Perry, of Englewood, Kansas, holds that in laying off the ditches it is necessary to forget all about directions of land lines and points of the compass, and be governed entirely by the contour of the surface to be irrigated (see Pl. VI).

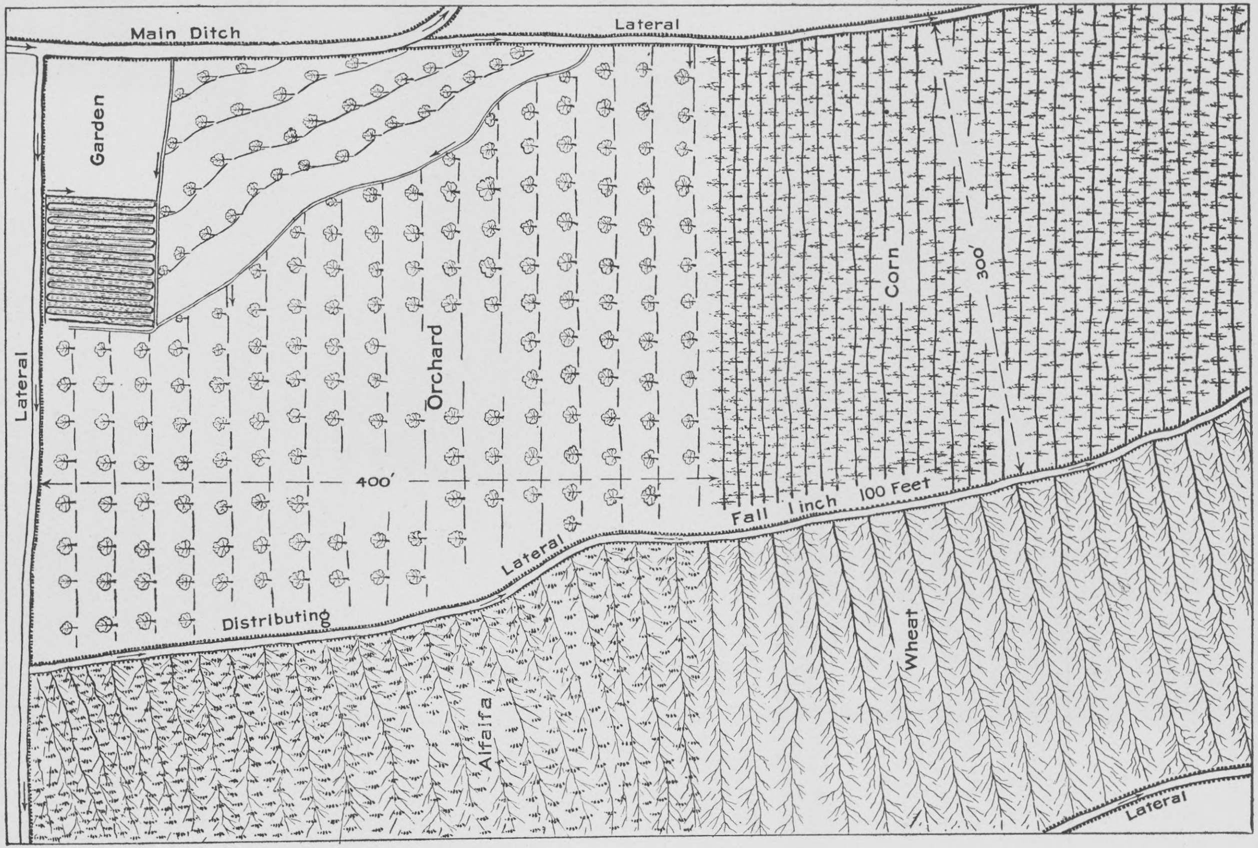
It is easily believed that the ditches must be carried along at a proper grade, and that the water can not be made to pass a hill by flowing up it, but only by following a course which gives a continuous though slight fall; but on the smooth surface of the plains, constituting not only the river bottoms but also the plateaus of the region, the unaided eye sees no reason why the water may not flow in one direction as well as another, or why it may not be made to follow the direction of the land lines without serious inconvenience. In some cases this can be done, but in others it is entirely impracticable.

These distributing ditches, or laterals, should be placed at such distances apart that the water may flow over the land from any ditch to the one next lower down the slope in so short a time that there will be no great difference between the amount of water taken up by the portions of the land on the different sides of the tract. This distance varies somewhat in different soils and on different slopes. Some have placed their ditches as far as 80 rods (1,320 feet) apart. Usually it will be found better to have the ditches not more than one-third this distance apart, and not infrequently it is better that the interval separating them be not more than 20 or even 16 rods.

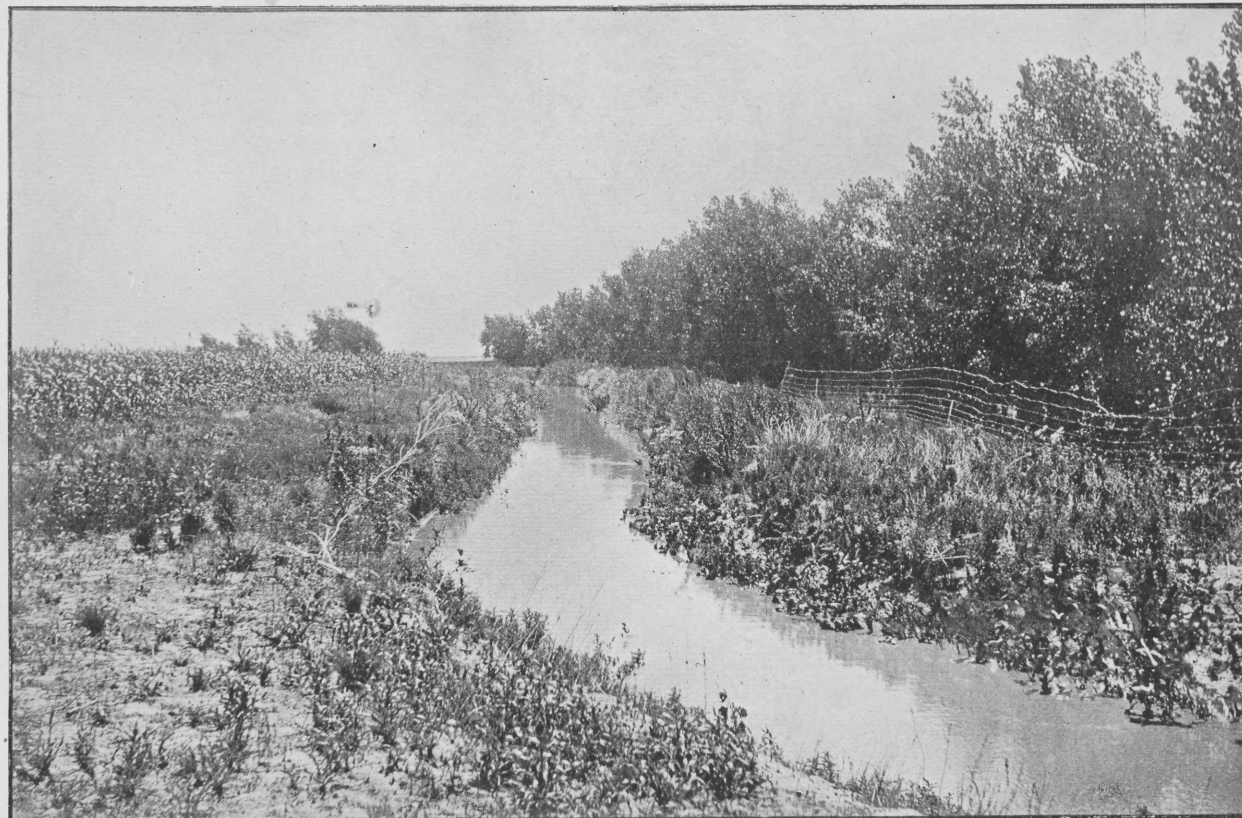
Water flows when the fall is very slight. In large ditches, free from short bends, a fall of 12 inches per mile produces a good current, while in such ditches a fall of 30 inches per mile often produces such a current as to cut the banks. For small ditches, such as are used for distributing from pumped-water reservoirs, a considerably greater fall is admissible and even desirable, and for laterals from which the water is made to flow over the land a fall of 1 inch per 100 feet is the correct standard. Where it is possible, they should be laid with such courses as will give them this fall.

In size irrigating ditches vary greatly. In some cases the lister furrow, with the loose earth removed, is large enough, while for the conveyance of water for large areas canals several feet wide and carrying water 2 or 3 feet deep are sometimes used. When Mr. Perry was irrigating but 1,200 acres of land with water from the Cimarron River, his main ditch was 16 feet wide at the bottom and carried water about 2 feet deep, and its sides sloped about 2 to 1. As his irrigating operations were increased beyond this amount, he enlarged the ditch in order to have command of a larger supply. But irrigation from a pumped-water reservoir is usually confined to a single farm, varying from 1 to, say, 40 acres in extent. For the 40-acre farm a ditch as shown in Pl. VII, 5 feet wide at the bottom and carrying water 15 inches deep, with sides sloping 2 to 1, will probably be found as large as needed. The laterals leading from this main ditch over the land to be irrigated will generally be much smaller than this perhaps not more than half as large, or even less, according to the amount of land to be served from them.

In the construction of ditches the implements used are the plow



PLAN OF PERRY FARM, CLARK COUNTY, KANSAS.



DISTRIBUTING DITCH.

and some sort of appliance for removing the loose earth from the ditch. The line of the ditch having been determined, furrows are plowed, throwing the soil from the middle to either side, and the size of the ditch controls the distance between the furrows of the first round. Very many ditches are made by plowing this first round in such a way as to leave the width of one furrow of a 14-inch plow in the middle. This is then turned out toward one side, and another furrow is turned from the bottom of this last furrow toward the other side of the ditch. It now remains only to remove the loose earth from the bottom of the ditch to the top of the banks. This operation is most rapidly performed by an instrument called an "A," from its resemblance in shape to that letter. It is constructed of planks, usually shod with steel or iron along the lower edges. After being suitably weighted it is drawn by means of horses, apex first, through the ditch. By suitably placing the weight, one side of the A, usually designated the land side, is made to follow along near the middle of the bottom of the ditch, while the other side throws about half of the loose earth out upon one bank. The return trip throws the other half of the loose earth out on the other bank, and, with the exception of a little finishing with the shovel, completes the ditch.

Larger ditches require more furrows and further use of the A, but are constructed in essentially the same manner. So also, in a ditch which at any place is to be made deeper than the average, a little extra work is done with these implements in that particular part. It is important in the construction of ditches that the banks be made tolerably uniform in height, and be so constructed as to carry water somewhat above the ordinary level of the land. For the distributing laterals banks 6 inches above the general level of the land to be irrigated are about right; if they are made a little higher, so as to be 6 inches after settling, so much the better. For rapid irrigation the ditches should be at all times capable of holding water to at least 4 inches above the level of the field.

DISTRIBUTING WATER.

In irrigating it is necessary to have water spread with as much uniformity as possible to all parts of the land. Fields which appear to the casual observer to be entirely without features of undulation are often found, when inspected with a view to irrigation, to possess elevations and depressions not suspected before. The practical irrigator finds that an elevation no greater than the thickness of a man's hand may turn the water entirely around a portion of his ground. So, also, a very slight depression is always found by the water, and is liable to be overirrigated, water-logged, and thereby caused to settle, increasing the disparity of the surface. It is therefore necessary that almost every piece of ground which is to be irrigated should be graded.

Grading may be done either before or after the construction of the ditches. It will usually be found that if the ditches are made first, or at least located, less grading will be required than would be considered necessary before the location of the ditches. There are various grading machines, all of which are operated by horsepower, and some of which are very simple. Some excellent graders are on the market at reasonable prices, but many farmers construct their own of planks, and with them do quite as good work as could be done with any machine built. Usually a few turns with the grader suffice to fill up a low place, and often at the same time to remove an elevation. It should be remembered that grading is of the nature of a permanent improvement. Once thoroughly done, it has never to be done again.

Water is thrown out of the ditches by means of dams, the use of which will be described presently. The most convenient form is the canvas dam. The materials used in the construction of a canvas dam are a piece of timber, usually a 2-by-4 scantling, long enough to reach across the top of the ditch from bank to bank; a small stick varying in length according to the width of the ditch to be dammed, but no longer than will lie across the bottom of the ditch without leaving any considerable space between the stick and the bottom; a brace or stick about one-third longer than the depth of the ditch, and a piece of canvas about one-third wider than the depth of the ditch and as long as the width of the ditch at the upper edge. The canvas is cut into a trapezoidal shape, somewhat resembling but larger than a section of the ditch. The long edge of the canvas is fastened to the scantling first described and the short edge to the small stick. It is well to have a little margin of the canvas below this short stick. The dam is placed by throwing the scantling across the ditch just below the point at which it is desired to divert the water, as shown in the illustration, Pl. IX. The canvas rests in the ditch, with the short stick lying across the bottom, far enough upstream from the location of the scantling to make the canvas nearly tight. The brace is placed with one end against the scantling and the other against the short stick, thus preventing the canvas from being washed back under the scantling. A little earth is thrown upon the loose edges of the canvas where it rests against the banks and against the bottom of the ditch, and the water is turned in. The weight of the water presses the canvas closely against the banks, so that there is scarcely any leakage. In some cases permanent dams with head gates are placed in the ditches, and this is more often done where ditches branch and it is desirable to divert the water to the one or the other branch.

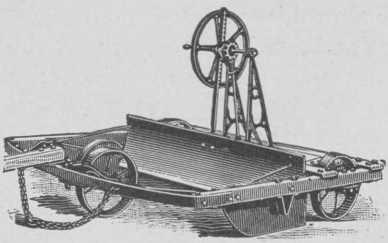
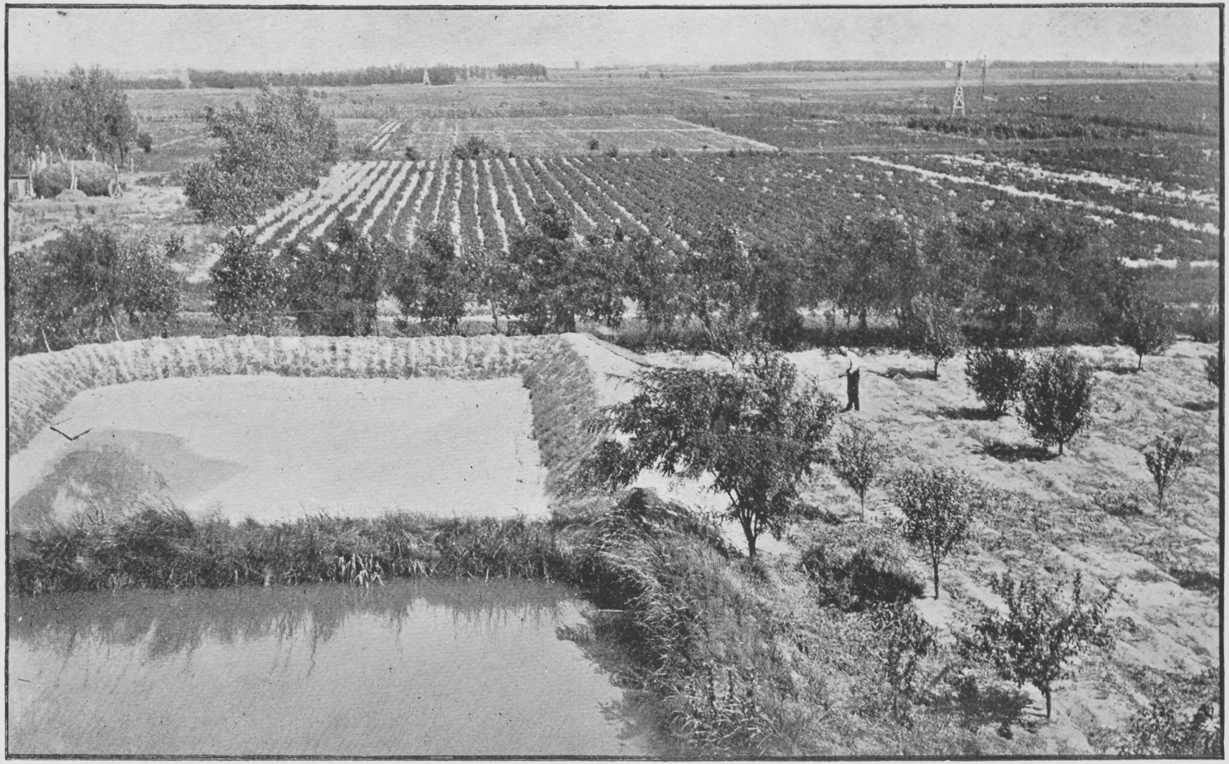


FIG. 4.—Land grader.



RESERVOIR AND GARDEN, AT GARDEN, KANSAS.

CANVAS DAM IN DISTRIBUTING DITCH.

A more primitive dam is sometimes made of earth, and such a dam is quite effectual and easily made in very small ditches. Sometimes a board is cut into the banks, and earth thrown in above it, making an effectual dam for ditches of considerable size; but for general purposes, where it is not worth while to put in permanent dams with flumes, canvas dams are most effective, and are placed and removed with less labor than any other. It is well that the irrigator be provided with at least two canvas dams suitable for each size of ditch from which he wishes to divert water.

METHODS OF WATERING.

That which has gone before is preliminary to the final object of applying water to the land at such times as the interest of the farmer or gardener suggests. There are two principal methods of watering, and a third is especially attractive to the novice and the amateur, and is not without its uses in some cases. For sowed grains, meadows, and pastures water is supplied to the land by flooding; that is, by allowing it to flow as completely as possible over the entire surface, but only in such volume as will not cause washing. For crops planted in rows and for orchards irrigation by furrows is generally preferred. The third method is by underground pipes, into which the water is passed, to be distributed through the soil by capillary attraction or surface tension, rising from below to near the surface, rather than passing from the surface downward, as in the other two methods.

Irrigation by flooding presupposes that the work of grading has been thoroughly done and that the ditches have been laid out and constructed with care. Take, for example, a meadow which has been thus prepared. The irrigator proceeds to a point in one of the laterals leading through this meadow 400 feet down the lateral from the point at which it enters the meadow. Here he places his canvas dam in the lateral, then admits the water. It will be remembered that the banks of these laterals are constructed so as to be 6 inches higher than the surface of the adjacent field. As soon as the water has risen 4 inches above the level of the field at the dam, or within 2 inches of the top of the bank, the irrigator makes a small opening in the bank just above the dam to the level of the water. At a distance of a rod or so farther upstream he makes another small opening, and so on throughout the 400 feet to the edge of the meadow. By this time the water is pouring out through all of these openings, giving a small stream at each. These streams spread over the ground and very soon widen into a broad sheet, which, with much irregularity of front, spreads downward toward the next lateral. If the grading has been well done, so as to give a uniform surface to the meadow, there should be no dry spots left after such an irrigation. If the grading has not been perfectly done and the water has inclined to flow around certains areas, it is necessary for the irrigator to take his shovel and, beginning at the point where the water begins to flow around, open a shallow channel through the highest part of the dry area, thus leading the water from the upper side and securing practically uniform irrigation. The water is allowed to continue running until this section of the meadow has been thoroughly moistened to such depth as the irrigator desires. With fresh ditches it is necessary to watch carefully that none of the openings in the bank becomes seriously washed and gets too large. When such trouble begins it is quite easily remedied by throwing in a shovelful or two of soil. When the ditches have become well settled, little trouble in this respect is experienced.

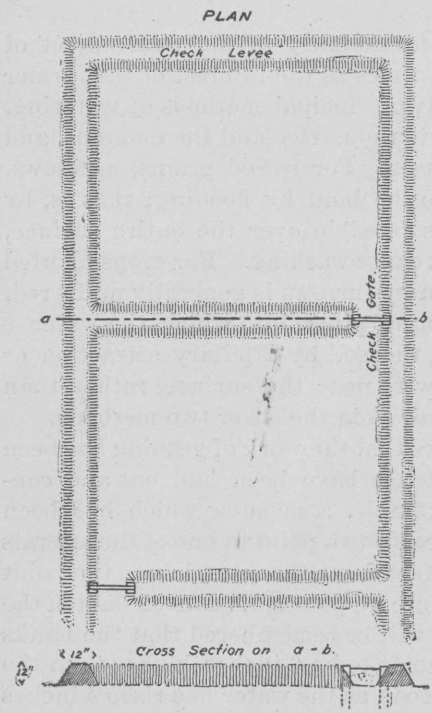


FIG. 5.—Diagram illustrating flooding in rectangular block.

While the water is flowing over this first section of the meadow the irrigator places a second canvas dam at a point about 400 feet farther down the lateral than that at which the first was placed. When the irrigation of the first section is completed, the dam first placed is removed and the water is allowed to flow down the lateral to the second dam. Openings are made in the ditch as before and the second section is irrigated in manner precisely like the first. The dams are thus removed to positions successively 400 feet farther downstream, and sections of this length are thus irrigated. The same course is pursued with each of the other laterals until the entire meadow is gone over.

It will be remembered that in speaking of ditches the proper fall was stated to be 1 inch to 100 feet. By making the opening nearest the dam so that its bottom is 4 inches above the level of the field, the water will rise to that height, and the bottom of the last opening, 400 feet farther up, will be just at the field level. If for any reason it has been necessary to give the ditch a greater fall than 1 inch to 100 feet, the dam is placed at correspondingly shorter intervals, unless the banks of the lateral have been made so high as to carry water more than 4 inches above the level of the field. For subsequent irrigations, if the ditches have not been disturbed, the dams may be placed in the same positions as at the first irrigation, and no new openings in the bank will be necessary,

EARTH DAM IN DISTRIBUTING DITCH.

the old openings being as available as at first, for on the removal of any dam the water immediately falls, so as to cease flowing through the openings above, the entire fall being 4 inches to the level of the openings of the next lower section. It is never necessary to close the openings when once properly made, and the only attention needed is to prevent or repair washes and to maintain all parts of the bank at sufficient height to prevent overflows other than at the points desired. Where an abundant head of water is available and old and well-settled ditches are used, it is often possible for the irrigator to attend to the dams and openings in more than one lateral, thus increasing the rapidity of the work. This method is applicable not only to meadows and such sowed crops as wheat, oats, rye, barley, etc., but it is sometimes used for corn or orchards, and indeed for almost everything except potatoes.

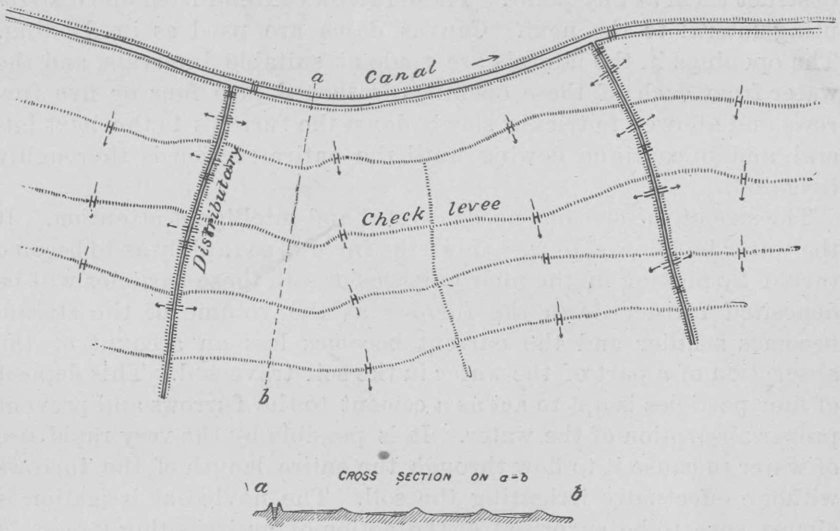


FIG. 6.—Diagram illustrating flooding within levees on irregular ground.

A modification of this system is used for some garden crops. Thus celery requires frequent and copious irrigation. The ground on which it is planted may be made into perfectly level beds, each having a border a few inches high completely inclosing it. The celery is irrigated by allowing sufficient water to run into this inclosure to cover the ground and settle into it until it is sufficiently moistened. Some celery growers irrigate in this way every two or three days from the time of planting until just before the celery is gathered.

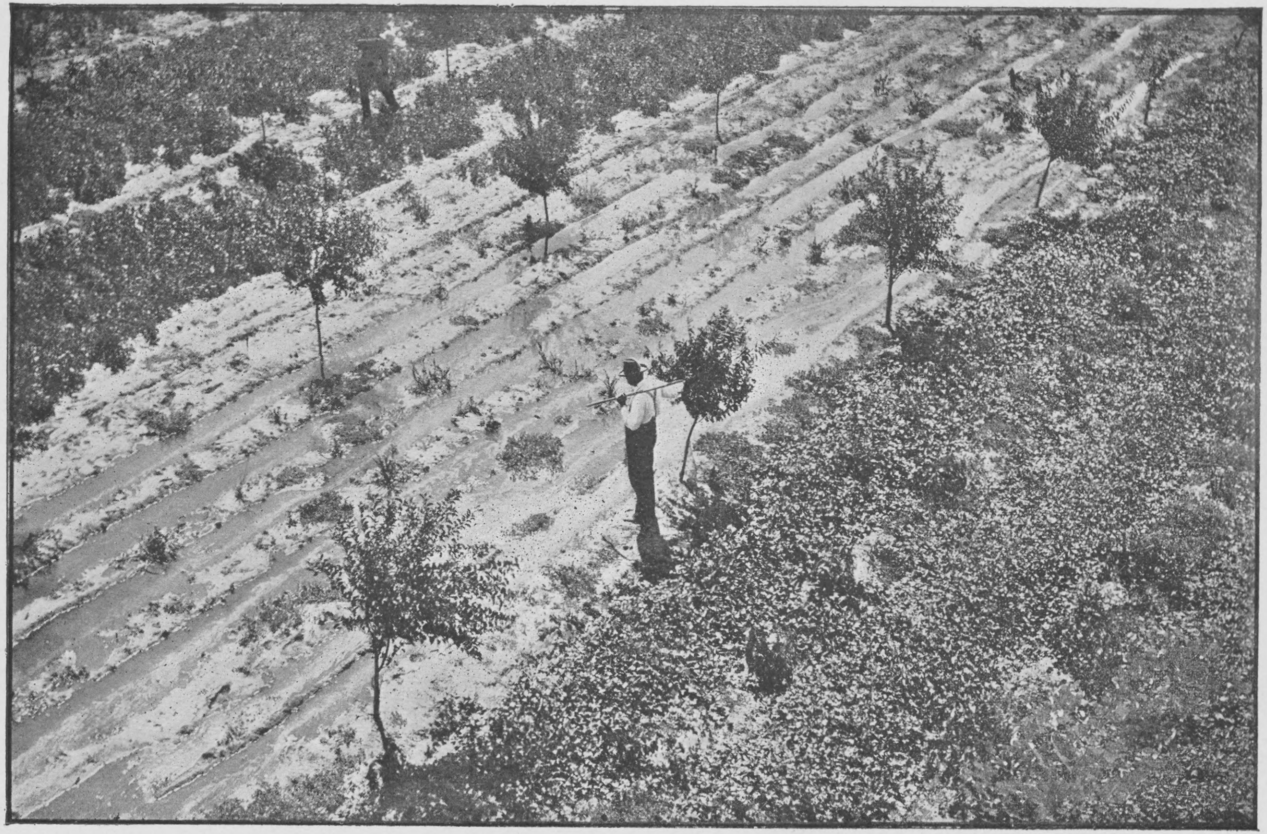
This bed system is sometimes applied to field work. The borders are made somewhat higher, and the beds are made to contain in some cases several acres each, according to the head of water available and the configuration of the surface. In field work the borders are made on contour lines, and are thrown up with the plow, and so rounded over the surface as to admit of mowing or cultivating over these elevations, so that the area of the embankments is neither wasted nor left to grow up in weeds.

This bed system, while at one time received with much favor for field work, is gradually giving way to the flooding system, as previously described, and to the furrow system, to follow.

In preparing for irrigation by the furrow system, the distributing laterals are made in all respects as described for the flooding system, except that it is practicable to have them somewhat farther apart. The rows of crops, as corn or potatoes, are made to terminate at the laterals from which they are to be irrigated, but it is not essential that they meet these laterals at right angles. When the water is to be applied, small furrows are made down the rows, care being taken that the loose earth does not roll back into the furrows so much as to obstruct them at any point. These furrows extend from one distributing lateral to the next. Canvas dams are used as in flooding. The openings in the laterals are made at suitable intervals, and the water from each of these openings is turned into four or five furrows and allowed to trickle slowly down the furrows to the next lateral, and to continue flowing until the entire section is thoroughly irrigated.

The size of the streams needs careful and intelligent attention. If the water be allowed to rush down the furrows so rapidly as to become turbid by picking up the finer particles of soil, these particles will be deposited farther down the furrows as the volume of the stream becomes smaller and the current becomes less on account of the absorption of a part of the water in the soil traversed. This deposit of fine particles is apt to act as a cement to the furrows and prevent proper absorption of the water. It is possible by the very rapid use of water to cause it to flow through the entire length of the furrows without effectually irrigating the soil. The novice at irrigation is almost sure to be surprised at the action of an irrigating stream in the furrows in a soft, plowed field. If the stream is very small, it may entirely disappear in the first rod or two of the furrow. If the stream is very large, it may carry away a considerable part of the soil from the first few feet or few rods of the furrow, and, as already stated, flow through without accomplishing the purpose of effectually moistening the land.

A properly regulated stream should flow through a furrow without becoming very turbid at any point, and should progress continuously, though slowly, throughout the length of the furrow. After it has flowed for a time, varying with the nature of the soil from a few to many hours, the land should be so thoroughly irrigated as to make it, especially if newly plowed, too soft to walk over without miring. Where the soil is of a flocculent structure and contains considerable vegetable material, this thorough irrigation may take place by the



FURROW IRRIGATION.

furrow system without greatly changing the loose and flocculent structure so desirable for rapid growth of vegetation. This is the acme of irrigation. Not every soil will retain this open structure, even under the most skillful handling of water. With many soils it is found that the effect of the artificial application of water is much like that of an exceedingly heavy and dashing rain, solidifying the soil by breaking down the open structure. It may be said that, as generally applied, irrigation leaves the soil compact and in condition to become very hard as it dries.

CULTIVATION.

The compacting of the soil after irrigation is remedied by cultivation of the surface as soon as the soil reaches a condition to be worked. This cultivation after irrigation serves the double purpose of checking the growth of weeds, which is sure to be copious, and of leaving a soil mulch of loose earth over the surface, which prevents the rapid evaporation of the moisture stored in the subsoil. The importance of cultivation after each irrigation can not be overestimated. In general the application of water without the subsequent cultivation is of little value, and, indeed, in many cases it is absolutely detrimental. The general experience is that, with the average soil, after the application of water the ground soon becomes very dry and very hard, and evaporation proceeds to rob both the soil and the subsoil of moisture with surprising rapidity. If the irrigator thinks to remedy the case by another irrigation, he usually only makes the matter worse, for the soil by this time, especially that along the borders of the furrows, has become quite thoroughly puddled, so that the second application of water with no intervening cultivation amounts to little more than flooding over the surface, with but slight moistening of the undersoil.

It may be stated in general that the irrigator who fails to cultivate soon after each irrigation will make a failure of irrigation. Indeed, in almost any part of the Great Plains, if either irrigation or cultivation must be omitted, it will be better to omit the irrigation than the cultivation for all such crops as admit of cultivation. The case with meadows and with sowed crops in general is somewhat different, the soil being to some extent protected and supported against excessive settling by the general distribution of the plants and roots. It is not improbable, however, that in the case of annuals, as wheat, rye, barley, and oats, it will be found profitable to make the drill rows far enough apart to admit of cultivation while the plants are small. In the case of meadows, especially with alfalfa, the influence of the extensive root growth is such as to keep the soil in condition favorable to rapid growth without cultivation. It is noticeable, however, that even alfalfa shows the marked influence of cultivation where a meadow of this legume joins a cultivated field.

SUBIRRIGATION.

The application of water by means of furrows placed at a considerable distance from the plants to be watered can be beneficial only in soils allowing a considerable lateral movement of the water. This percolation may take place in certain soils through a space of several feet or rods, while in others the influence of the water apparently is not felt for more than a few inches. In cases where the soil and subsoil have a structure such that water moves laterally through them with considerable ease, the theoretically perfect method of applying it is through pipes laid underground below the reach of the plow and perforated, so that when filled the moisture will be uniformly distributed near the roots of the plants. This does away with all losses from evaporation and from saturating the sides and bottom of the open ditches. Unfortunately, however, this method has been found practicable only to a limited extent. Many soils do not transmit the water freely, while others are underlain by a gravelly or open subsoil through which the water escapes downward with far greater rapidity than it can move sideways. Another serious obstacle to the success of this form of irrigation lies in the fact that the little roots of the trees and plants are induced by the moisture to reach out toward the pipes, seeking every crevice or perforation, and soon stopping these up with interlacing rootlets. In California many instances are given where great expense was incurred in laying out an elaborate system of perforated or porous pipes. Irrigation through these was highly successful for one or two years, and then became less so, until the method was abandoned and the pipes taken up or else openings made to the surface, so that the water could come up and spread as from a hydrant over the plat to be wet.

The term "subirrigation" is often applied to the conditions where the subsoil is saturated either artificially or even naturally. For example, many lowlands along streams are commonly said to be subirrigated from the fact that the underlying gravels are filled with ground water which extends up high enough to be available for the use of deep-rooted plants. The word is also applied to similar cases where, by excessive use of water on lands higher up, the low grounds have been so completely filled by seepage that it is no longer necessary to flow water over the surface. This is, however, hardly a proper use of the term, as it can better be confined to the intentional application of water beneath the surface by pipes or similar devices.

The method of irrigating by underground pipes is one that appeals very strongly to the fancy of the novice. It has been repeatedly tried, and in most cases has been abandoned. This does not necessarily prove that the plan is useless or impracticable, and the fact that some have continued its use makes it worth while to describe it and to examine somewhat the conditions of its trials and the probability

SATURATING GROUND.

of its usefulness. The plan is, in general, to place porous drain tiles far enough beneath the surface of the cultivated land to be out of the way of the plow and other implements of cultivation, and to have the lines of this tile so connected with the source of water supply that they may be filled at will. Reports of the use of this method in California state, as noted above, that the roots of the trees and plants penetrated the tile at the joints, or at any opening where the water could get out, and formed mats of small rootlets within the pipe, so as to effectually obstruct the flow of water. In the gravelly and open soils of Utah it was found that on emerging from the pipe lines the water was very little inclined to distribute itself laterally, but yielded to gravity and went down, so that only narrow strips were well irrigated, and these at considerable depth below the surface, the water having little inclination to rise above the pipe lines. At the Wisconsin experiment station the water came to the surface above the pipe lines, but the spaces between were not well irrigated. A photograph of a tile-irrigated field or plat showed by dark lines the location of the pipes, while the intervening surfaces were entirely dry.

In Osborne County, Kansas, very satisfactory results have been reported from pipe irrigation, the water having been distributed laterally, so that almost ideal irrigation was obtained. The objection noted in California is one for which it is difficult to conceive an effectual remedy. It is undoubtedly true, however, that a stoppage in a pipe may be easily located, and since the pipes are placed at no great depth below the surface, it should not be a serious task to remove a single obstruction. But if the stoppages should be very numerous, the expense of keeping the lines open might exceed the advantages claimed for the system. In Utah the tendency of the water to go immediately downward instead of laterally was due to the open, gravelly subsoil. A consideration of the description of other experiments suggests that the difficulty encountered—that of the water coming to the surface immediately over the pipe lines, but not distributing well laterally—may be overcome by a modification of the work. It appears that in these experiments the pipes were put in trenches in the subsoil and the surface cultivation was conducted in the usual way. The water had little opportunity to circulate laterally until it had risen to

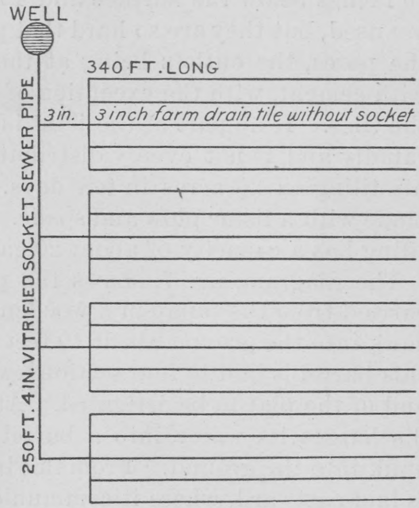


FIG. 7.—Plan of subirrigating system.

the bottom of the cultivated stratum. In the experiments in Osborne County, Kansas, the entire subsoil was broken to the depth at which the pipes were laid. The water moved laterally over the compact, undisturbed lower subsoil and rose to the surface quite uniformly over the entire tract. Possibly if the subsoil in the Wisconsin experiments had been treated in the same way, the results might have been modified and made favorable rather than unfavorable.

The plant of one of the successful tile irrigators of Osborne County, Kansas, Mr. Andrew Linn, is described as follows: The ground was plowed 6 inches deep and subsoiled about 8 inches, altogether stirring the soil to the depth of about 14 inches. The ground was plowed north and south, the tiling laid east and west. The land slopes slightly to the east and south. An arrangement is made to use the plant as a drainage system when there is too much rain. Three-inch tiles are laid 15 inches below the surface and 10 feet apart. Unglazed drain tiles are used, but they are so hard that practically no water passes through the pores, the outlets being at the joints. These joints are closed with cement, with the exception of about an inch on the underside of the tiles. If no part of the joint is cemented, the water flows out too rapidly and is not evenly distributed. Mr. Linn laid and cemented his tiling on 2½ acres in ten days. The ditches for the tiling were made with a lister plow and spade. The pump to supply water to the tiling has a capacity of about 20 gallons per minute.

The diagram, fig. 7, shows the plan of the system. The water is carried from the pump in a wooden conductor and flows into a barrel sunk into the ground about 10 feet away. A 4-inch sewer pipe from this barrel is laid in four sections extending southward across the west end of the plat to be irrigated. At the end of each section the pipe discharges its water into a barrel (not shown in the diagram), also sunk into the ground. From this barrel a 3-inch pipe, 8 feet in length, is laid eastward, where it communicates with a 3-inch pipe laid north and south about 40 feet. To this pipe are connected five 3-inch drain tiles extending eastward entirely across the plat and 10 feet apart. The lot is thus divided into sections, each independent of the others, and facilitating the irrigation of any section at will.

Mr. Linn is satisfied with the results of irrigation with this plant, but as yet no comparison has been made with those obtained by surface irrigation under otherwise similar conditions. The cost of such an arrangement is certainly against it, and will probably, for a long time at least, preclude its use except for gardens or for farming on a very small scale. But the experiments of Mr. Linn and some of his neighbors have shown that with such soil and subsoil as they possess it is perfectly practicable to get a good distribution of water by means of underground pipes. Their plan has been to pump the soil and subsoil full of water during the fall and winter, saturating it to a depth of 6 or 8 feet.

After this it was necessary only to supply the water transpired by vegetation and lost by evaporation, the loss being very small on account of the fact that no crust was formed on the surface, and the flocculent, open structure of the soil was little interfered with by this method of applying water. It remains to be seen whether the plan of cementing the joints of the hard-burned tile, except an inch on the under side, will prevent the entrance of roots to the extent of stopping the circulation of water through the pipes. This method has been used also by Dr. Hudson, of Osborne, who has expressed satisfaction with the results. Other than tile pipes have been used for this purpose. Small pipes made of galvanized iron and perforated with very small holes, or preferably with an open seam, have been used and satisfactory results reported. The following description has been condensed from a statement given by Mr. Alex. Richter, of Hollyrood, Kansas, who has used the open-seam pipes.

The first precaution is to ascertain whether the structure of the soil and subsoil is such that subirrigation is practicable, as it is a useless expenditure of money to lay pipes where the conditions are such that the water will not spread laterally to the plants. In some localities the subsoil is so porous that the water applied beneath the surface sinks immediately and can not be had by the roots of any of the plants except those in the immediate vicinity of the source of supply. This is especially the case on the bottom lands along streams where the surface soil rests upon gravel or beds of sand. Where, on the contrary, the subsoil is comparatively impervious, and above this the structure is such that the water is transmitted horizontally, systems of subirrigation can be introduced to great advantage. For example, the following experiment was tried: During a dry season a pipe 10 feet long was laid 10 inches deep in the middle of four rows of string beans, these being about 5 feet apart. Into the pipe 12 quarts of water were poured, and the same amount was sprinkled on four other rows of string beans in all respects similar to the first. In the case of the rows watered by the pipe the beans did well, while in the other rows they died. The same amount of water was given to each.

In 1895 many experiments were made by different farmers, some putting pipes in rows 5 feet apart, others 8 or 16 feet, and in one case 27 feet. Different depths also were tried, some being 14 inches, others 18, and still others 2 feet. During the first five months nearly all of these were satisfactory, but after that period difficulty was found by the persons who had laid the pipes from 18 to 24 inches beneath the surface. By digging down it was found that the deeper pipes had been placed so low as to be embedded in the clay subsoil, and that this did not allow the water to spread freely. By raising the pipes about 6 inches, well above the top of the clay, the water percolated freely. For vegetables it was found that pipes give the best success when laid from 8 to 10 feet apart, while for orchards a single row of pipes was sufficient between alternate rows of trees, these pipes being placed from 10 to 12 inches in depth. It was also found that the moisture was rendered more efficient by using fertilizers.

One of the most common mistakes at first made has been in giving too great a slope or inclination to the pipes. If laid on ground which has a decided fall the water runs to the lower end before it can escape in considerable part through the opening along the side. For this reason the pipes should be laid very nearly level, but if a considerable slope can not be avoided it has been found best to have cut-offs in the pipe every 10 or 20 feet to check the flow. Another way is to run the main pipe on the down grade and connect this with irrigating pipes branching from it with suitable valves or cut-offs, so that the water can be turned into the branches. The preferred length of irrigating pipe is about 200 feet. Sometimes this can be connected at both ends with the main supply pipes to advantage. The main supply pipe is proportioned according to the amount of water to be carried. In general for gardens and orchards it is 1¼ inches in diameter. The sheet-iron irrigating pipe leading from this has an open seam along its length and is usually seven-eighths of an inch in diameter, although smaller sizes can be used for flower beds. The cost varies according to the amount used, but in one case where 3 acres were provided, 2 of these being orchard and the remaining acre devoted to potatoes, watermelons, and other vegetables, the entire cost was $63. In this case the watermelons alone paid the cost of the pipe. One man can lay nearly 3,000 feet in a day, covering it up by means of a plow.

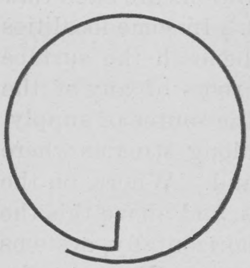


FIG. 8.—Section of open-seam pipe.

There is a notable difference in the distribution of moisture when the subirrigating pipes are laid above the surface of the clay and when they are put down in it. In the first case, when the pipe is buried in the pervious soil slightly above the impervious clayey subsoil, the water spreads laterally upon the surface of the latter, moistening the ground upward while spreading out beneath the surface. In the second case, when the pipe is within the clay, the water can not spread laterally, but rises slowly and moistens only a narrow belt immediately above the pipe, not finding its way as rapidly as in the other case along the surface of the clay.

This difference in behavior is illustrated by an experiment in which two pipes were laid above the subsoil and five pipes below the clay. The two pipes were able to deliver far more water than the five more deeply buried. An examination by a test pit showed that although the surface was dry above the five pipes, there was standing water in the clay. This fairly uniform distribution of water from the pipes when laid above the subsoil is said to obviate the difficulty found with the roots of trees. The great objection to this form of subirrigation has been that after one or two years the fine roots of plants seeking out the water inclose the conducting pipe and penetrate every opening or crack, finally completely obstructing the flow of water. Where, however, the moisture is distributed uniformly through the soil, the roots are not impelled directly toward the pipe. Cases have been reported where pipe has been used for three years successfully at a distance of only about a yard from a row of trees.

AMOUNT OF WATER REQUIRED.

There are two ways in which quantities of water used in irrigation are expressed. One is in terms of the rate of flow, as, for example, that of a river; the other is in quantities of water, such as would be held by a reservoir. In the first case we speak of a stream as averaging through the month of August 10 second-feet or 500 miner's inches. In the second case we speak of a reservoir as holding, in round numbers, 6.46 million gallons, or 862,000 cubic feet, or 19.8 acre-feet. Each of these can be converted into the other by simple computations. Where water is spoken of according to the rate of flow, the total volume can be obtained only by assuming a certain length of time during which the flow continues. On the other hand, the volume of water, as, for example, that stored in a reservoir, can be converted into rate of flow by figures based upon the number of days or seconds during which the quantity is to be discharged.

In discussing rates of flow of a natural stream, the cubic foot per second or second-foot has been generally adopted as the standard, and is rapidly displacing the older, indefinite term—miner's inch.

The cubic foot per second, or second-foot, is the rate of delivery of a stream 1 foot wide and 1 foot deep, flowing at the average rate of 1 foot per second. The quantity is, of course, independent of the shape or velocity of the water; a second-foot will be delivered by a pipe 6 inches in diameter in which the average flow is a trifle over 5 feet per second, or by a ditch having a cross section of 4 square feet and a sluggish current of only 3 inches per second.

The miner's inch is a unit adopted for convenience by the hydraulic miners of the West, and, being easily arrived at through rough devices, has been largely employed throughout the arid region in estimating the quantities of flowing water. The chief objection to it is its indefinite character. One miner's inch may be 20 or 25 per cent larger than another, although both are measured according to established rule or customs. In early days, when water was abundant and it had little value, there was no especial demand for accuracy in its measurement, and the crude devices sufficed for all practical purposes; but when the streams came to be used for agriculture and it was appreciated that values resided in the flowing water rather than in the land, it made considerable difference to a farmer whether his miner's inch of water was large or small. To avoid confusion and litigation, the term "miner's inch" has therefore been largely done away with and quantities are given in fractions of a second-foot. In California the miner's inch is now given as one-fiftieth of a second-foot, while in Colorado and many other of the Rocky Mountain States it is nearer the fortieth part of a second-foot. In other words, the Colorado miner's inch is considerably the larger.

The second method of stating the quantity of water—that by actual volumes rather than by rate of flow—is in all respects the more accurate and desirable, and is the only practicable means in localities such as those on the Great Plains, where water must be pumped or stored and is not running continuously to waste when not used, as is the case along the larger streams of the arid region. The units employed may be the gallon, the cubic foot, or the acre-foot. The United States gallon, as defined by statute, contains 231 inches; 7.48 gallons make a cubic foot, or 1 gallon is 0.13368 of a cubic foot. The chief disadvantage of the gallon as a unit is that it is too small and requires large figures to express the amount needed for irrigation. It has also the additional disadvantage that there are other gallons of other sizes in use, so that confusion occasionally arises.

The cubic foot is a definite quantity and is very convenient for use in computations of the amount of water required. By its use the capacity of reservoirs can be readily computed, since their dimensions are usually expressed in feet. It is, however, like the gallon, too small for convenience in many estimates, and in practice it has been largely replaced by the acre-foot. This latter term implies a quantity equivalent to the amount of water covering 1 acre to the depth of 1 foot. In other words, 1 acre-foot equals 43,560 cubic feet. This quantity—an acre-foot—does not imply that the water must be spread out 1 foot in depth, for the 43,560 cubic feet can be placed in a reservoir of any shape and still be an acre-foot. It may be held, for example, in a pond 100 feet square and to a depth of a little over 4.3 feet, or it may be in a tank 20 by 50 feet and 43.56 feet deep. There is a convenient relation between the acre-foot and the cubic foot per second, or second-foot. The latter flowing for one day (twenty-four hours) very nearly equals 2 acre-feet; that is to say, a stream 1 foot wide and 1 foot deep, flowing at an average velocity of 1 foot per second, will in one day, or 86,400 seconds, cover a surface of 1 acre to a depth of very nearly 2 feet.

The term "duty of water" has been employed to express the relation which exists between the quantity of water used and the area of land irrigated. For example, if a stream of water equivalent to 1 cubic foot per second irrigates 100 acres, the water duty at that place is stated as being 100 acres to the second-foot. This water duty may be arrived at from two opposite directions. First, as given above, by taking actual instances of the measured amount of water applied; and second, by starting at the other end and estimating the theoretical amount which the plants require and the quantity which must be wasted in wetting the ground before the water can be available for the need of the plants. Neither of these is wholly satisfactory, and there has not as yet been obtained a sufficiently large body of facts to enable conclusions of general applicability to be drawn. Taking any one crop through successive years, the amount of water actually used varies so widely that it is doubtful whether any figures yet published can be implicitly relied upon.

A large number of experiments have been carried on, not only in Europe but in this country, to show the amount of water exhaled by plants. The results of these, as above stated, are discordant, but as a rough statement it may be said that the plants have transpired during their growth a weight of water from 300 to 500 times that of the weight of dry matter. In this country various agricultural stations have obtained and still are obtaining data bearing upon this point. Among the best of the published results are the series of experiments conducted by Prof. F. H. King at the Wisconsin agricultural station. These are of particular value in this connection as showing the amount of water required by plants even in a humid climate. The results of the observations for 1892 show the following amounts of water consumed per pound of dry material produced:

Crop.	Water consumed.
	Pounds.
Barley	375
Oats	526
Corn	317
Clover	564
Pease	477

The data given above have been combined with those obtained for 1891 and computed in other units, giving the corresponding depth of water used in the production of the plants. These results are shown in simplest form in the following table:

Crop.	Year.	Water consumed.
		Inches.
Barley	1891	13.2
Do	1892	23.5
Oats	1891	19.7
Do	1892	19.0
Corn	1891	26.4
Do	1892	25.1
Clover	1892	29.7
Pease	1892	16.9

From the above table it is to be observed that the least amount of water used was by the barley in 1891, and it should be noted that the product for this year was only about half that for 1892, while nearly double the amount of water was used. It is probable, therefore, that if the barley had received or used as much water as the same crop in 1892, the production of dry matter would have been greatly increased.

It has been found that there is a great range in the amount of water employed by various plants in the process of building their tissues, and that not only do the different species stand widely apart in this respect, but even individuals of any one species at the successive stages of life or with alternations of climatic conditions transpire water more or less freely. As previously noted, the experiments, when reduced to a common basis, show a wide range in results, depending largely not only upon the conditions under which the tests were carried on but also upon the assumptions necessarily made in reduction to the same form of statement. Thus the water used by a crop of wheat is from 9.3 to 29.8 inches in depth, averaging 17.9 inches; by barley, from 4 to 30 inches; the same experiments in successive years obtaining 13 and 23.5 inches, the difference, however, being in part accounted for by the increase in yield.

In actual crop production, however, it is necessary not only to satisfy the thirst of the plant but also to fill certain demands of the soil necessitated by its composition, structure, and exposure to the air. A certain amount of water must be given to the soil before the plant can obtain any for itself, and, according to the skill of cultivation, more or less of this water will be taken up directly by the air or by weeds. The process of getting the water to the crop, usually in open-earth channels, is also more or less wasteful, so that beyond the plant's needs there is always to be added a variable percentage to cover these various losses. Many of these losses may be reduced or prevented by more perfect systems of irrigation and cultivation, but there is always a limit to expenditures in this direction set by the market value of the product. In other words, it will not pay to push water economy in this direction beyond moderate efforts.

To obtain valid conclusions as to the total amount of water required by the plant, together with that portion lost in transit in the irrigating channels and in the soil while waiting for the demands of vegetation, it is necessary to resort to the results of field tests made in various localities under local conditions of soil and climate. There are, unfortunately, comparatively few data as yet sufficiently complete for generalization, and these, as might be expected from an analysis of the matter relating to plant transpiration, offer wide discrepancies.

Experimental data are still lacking as to the exact amount of water required for the proper moistening of plains soils to any depth. It is not unusual with alfalfa to apply 6 inches of water, or over 680 tons per acre, at a single irrigation, but with the usual field crops it is probable that 3 acre-inches at an application is more usual than a larger quantity. Experience of irrigators generally favors the application of enough water to moisten the soil to a considerable depth, say $1\frac{1}{2}$ to $2\frac{1}{2}$ feet, and then by cultivation producing a mulch of fine soil on the surface to retard evaporation, thus retaining the water of a single irrigation for the use of the deeper roots of the plants for a considerable period, rather than the more frequent application of small quantities, which, by moistening only that portion of the soil very near to the surface, encourages the growth of roots in that portion of the soil which soon becomes dry. Such irrigation leads to spasmodic and irregular growth and often to serious injury to the plant from drought, even though very frequently watered. For general purposes it is undoubtedly the best plan to have the subsoil well moistened early in the season and to keep up the supply of moisture by such copious subsequent irrigation as will encourage the development of deep roots and maintain the uniform maximum growth of the plants.

A convenient figure in estimating the quantity of water to be applied to orchard and ordinary crops at a single irrigation is 100,000 gallons per acre. This will allow of some loss by seepage in the ditches, and usually moistens the soil to a good depth if judiciously applied, and can by the furrow system generally be so applied as to leave the soil in good condition for growth.

The quantity of land which may be irrigated by a single man in a given time is exceedingly variable, and depends greatly upon the skill with which the land has been graded and the ditches have been laid out and constructed. Twenty acres per day may be as easily irrigated under some conditions as 1 or 2 acres under other conditions. In garden operations, of course, the areas covered are usually much less than in the big fields, and a man may sometimes spend a whole day on very much less than an acre and have no reason to chide himself for inefficiency.

WINTER IRRIGATION.

On the plains the winter and early spring months are usually dry, and the soil is sometimes almost as devoid of moisture at the opening of spring as during subsequent droughts. This powdery soil is easily worked, and some have thought it in favorable condition for the reception of seed, and that copious watering later would be sufficient to insure the full benefit of irrigation. But disappointments have sometimes resulted, scarcely better crops being realized than where no water was applied artificially. On the other hand, where similar soil has been thoroughly moistened by the late winter or early spring rains, or by winter irrigation, the fertility of the soil has been amply demonstrated. Whatever may be the explanation of the fact, it has been found by nearly all observant irrigators of the plains that winter irrigation, thoroughly done, serves very well the double process of fertilizing and moistening. Mr. Perry states that after his eight years of extensive experience in irrigation, he has had the best average results where he has thoroughly saturated the soil to a depth of 2 or 3 feet during the fall or winter or very early spring, and then has cultivated his crops on this land without subsequent irrigation. Mr. C. B. Huffman, of Enterprise, Kansas, has found that land thoroughly irrigated and well cultivated during the season of 1895, and afterwards sown in wheat, produced suprisingly well in 1896 without any irrigation after the wheat was sown, while similar land that had not been irrigated gave a very poor yield. The general experience of orchardists favors winter irrigation. Not unlikely, future practice in the application of water will consist in thoroughly wetting the soil during the winter and in such subsequent irrigation as may be found desirable to maintain the maximum growth, the larger quantity of water being applied in the winter, when evaporation is at a minimum.

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